PRESSURE DROP OF DIFFERENT FLOW PATTERN IN MULTIPHASE FLOW SYSTEM

MOHAMMAD HAFIZEZAZMI BIN AJAMAIN

Thesis submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Chemical Engineering

Faculty of Chemical & Natural Resources Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2015

ABSTRACT

Multiphase flow is not an old issue to be discussed. Pressure drop and heat transfer under multiphase flow are very complicated to predict. Lots of empirical correlations have been made to predict pressure drop in pipelines under multiphase condition. Example of correlation used to predict pressure drop is Petalas-Aziz correlation, Begss-Brill correlation and Flannigan correlation. Under multiphase condition, different types of flow pattern can happen. In predicting pressure drop flow pattern is considered because different flow pattern will give a different pressure drop. In this study flow pattern is consider to determine the flow pattern. Flow pattern used is intermittent, stratified, annular and bubble flow. After determining the flow pattern, three empirical correlations used to predict the pressure drop which is Petalas-Aziz correlation, Beggs and Brill correlation and Flannigan correlation. Thus, to determine the flow pattern and pressure drop mathematical programming software is used which is FORTRAN. Using the programming code, predicting the pressure drop and determining flow pattern user can use it to design a better pipeline to encounter pressure loss.

ABSTRAK

Aliran berbilang bukan isu lama yang akan dibincangkan. Kejatuhan tekanan dan pemindahan haba di bawah aliran berbilang fasa yang sangat rumit untuk diramalkan. Banyak korelasi empirik telah dibuat untuk meramal kejatuhan tekanan dalam saluran paip dalam keadaan aliran yang berbeza. Contoh korelasi digunakan untuk meramalkan kejatuhan tekanan adalah korelasi Petalas-Aziz, korelasi Begss-Brill dan korelasi Flannigan. Di bawah keadaan berbilang fasa, pelbagai jenis corak aliran boleh berlaku. Aliran yang. Dalam pola ini aliran pengajian adalah mempertimbangkan untuk menentukan corak aliran. Corak aliran yang digunakan adalah terputus-putus, berlapis, anulus dan aliran gelembung. Aliran yang berbeza akan menghasilkan penuruan tekanan yang berbeza. Tiga korelasi empirikal digunakan untuk meramalkan kejatuhan tekanan yang Petalas-Aziz, Beggs dan Brill dan Flannigan. Oleh itu, untuk menentukan corak aliran dan penurunan tekanan satu perisian pengaturcaraan matematik digunakan iaitu FORTRAN. Kod pengaturcaraan digunakan meramalkan kejatuhan tekanan dan menentukan corak aliran. Pengguna boleh menggunakannya untuk mereka bentuk saluran paip yang lebih baik untuk menghadapi kehilangan tekanan.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

D	Pipe diameter
k	Wall roughness
u_{SL}	Superficial liquid viscosity
u_{SG}	Superficial gas viscosity
ρ_L	Liquid density
ρ_G	Gas density
ρ_m	Mixture density
μ_L	Liquid viscosity
μ_G	Gas viscosity
u_m	Mixture viscosity
Re_{SL}	Superficial liquid Reynolds number
Re_{SG}	Superficial gas Reynolds number
f	Fanning friction factor
f_m	Mixture Fanning friction factor
F_L	Liquid Froude number
F_G	Gas Froude number
g	Acceleration of gravity
Y	Inclination or gravity parameter
X	Lockhart Martinelli parameter
Kh	Kelvin-Helmholtz instability
$Kh_{critical}$	Kelvin-Helmholtz instability critical
α_L	Liquid holdup
α_G	Gas holdup
d_{max}	Maximum bubble size
d_{def}	Critical bubble size for deformation
d_{migr}	Bubble migration to the upper part of the pipe
σ	Surface tension
E_L	In-situ liquid volume fraction
L_1, L_2	Length of pipe
A	Surface area
F_{rm}	Froude mixture number

F_{NS}	No-slip friction factor
F_{tp}	Two phase friction factor
P_f	Friction pressure
P_{HH}	Hydrostatic pressure
C_0	Velocity distribution coefficient

1 INTRODUCTION

1.1 Motivation and statement of problem

Single phase is defined when one of the matter exist as one states such as a liquid, a solid or a gas. While multiphase flow defined as simultaneous flow of several phases. It can exist as two phase flow or three phase flow. Examples of two phase flow are solid-solid flow, solid-liquid flow, liquid-liquid flow or gas-liquid flow. Flow of mud and slurries is an example of two phase flow. Three phase flow is solid, liquid and gas flow simultaneously. Oil and gas transportation through pipelines always experience multiphase flow. (Awad, 2012)

Multiphase is very important oil and gas transportation and it is not unique in oil and gas industry. In the past three decades, researcher have do some efforts to understand multiphase flow. Different empirical correlations had been made to predict flow pattern liquid holdup, friction factor and pressure-gradient equation in pipelines under multiphase flow condition (Brill, 2010).

In this study the problem statements is programming the prediction of pressure drop in pipelines under multiphase condition. A programme will be developed using FORTRAN software to ease the prediction. Different correlation will be used to compare the pressure drop under certain condition. Since flow pattern is considered in this study thus the correlation that will be used is Petalas and Aziz correlation and Beggs and Brill correlation. Other correlation that not refers to the flow also will be used to compare the results. The correlation is Flannigan Correlation.

N. Petalas and K. Aziz have developed their model to improve previous pressure drop correlation. The correlation is applicable for all types of pipe geometries, fluid properties and flow in all direction. It is improved with a mechanistic approach mixed with empirical closure relationships. With this combination the pressure drop prediction and holdup in pipes can be calculated in more extensive range and conditions. (Petalas & Aziz, 2000)

H. Dale Beggs and James P.Brill has developed their own correlation for pressure drop in two phase system. They developed an air-water system by testing it in 1 to 1 1/5 inch pipes. Furthermore, different angle of pipes are tested to measure the pressure drop (James & H., 1973).

Flannigan correlation (1985) is the extension of Panhandle single-phase correlation. The correlation is good for a horizontal pipelines but it cannot used more or less 10 degrees from the horizontal.

Flow pattern will give a different result of pressure drop. Up until now there’s no correlation that can predict the entire flow pattern accurately. Few assumptions will be made in order the programme can work. The flow patterns are based on Madhane et, al. horizontal flow regime map.

Different flow pattern will result a different pressure drop. Petalas-Aziz correlation and Beggs-Brill correlation refer to the flow pattern before calculating the pressure drop. Thus, in this studies flow pattern will be determined first either it is stratified, intermittent, dispersed and bubble flow pattern. The pressure drop is calculated based on the types of flow pattern.

.

1.2 Objectives

Two objectives are set in order to achieve these studies. First is to develop a program to identify the flow pattern of multiphase flow. There are 4 types flow patterns which are bubble, stratified, annular and intermittent flow pattern. The flow pattern is based on Mandhane et al. horizontal flow regime map.

A second objective is to calculate and compare the pressure drop based on the flow pattern by using different correlations. The calculation will be determined automatically by programming software which is FORTRAN.

1.3 Scope of this research

The correlations that will be used are Petalas-Aziz, Beggs-Brill and Flannigan correlations. The angle of the pipe is horizontal thus Madhane et, al. horizontal flow regime map is considered.

Furthermore, type of multiphase flow is liquid and gas. Last but not least the flow patterns that will be calculated in this studies are bubble, annular, stratified and intermittent flow pattern.

1.4 Main contribution of this work

Main contribution of this study is to understand the concept of flow pattern as well as pressure drop in multiphase flow system. Furthermore the programming code can be used in academic field to determine the pressure drop of different flow pattern in multiphase flow system Thus, designing a pipeline can be easier by using the programming code. I thank you from the bottom of my heart to Professor Dr. Zulkefli Yaacob for helping me doing this study.

1.5 Organisation of this thesis

The structure of the reminder of the thesis is outlined as follow:

Chapter 1 involves the overview of this thesis. It includes general introduction of pressure drop of different flow pattern in multiphase flow system. Furthermore it contains the problem statement, objectives and scopes.

Chapter 2 will give a detailed reviews on pressure drop as well as multiphase flow. A detailed work on flow pattern also included where all types of flow pattern in horizontal work are included. Furthermore the types of correlation also listed.

Chapter 3 is where methodology of this projects. It shows how the software will run through the formula to calculate pressure drop. Some of assumptions are made to make the software to run as well as the parameter that will be used.

Chapter 4 is the most important part where results based on the calculation are discussed.

Chapter 5 is the final part of this thesis it concluded overall studies.

2 LITERATURE REVIEW

2.1 *Pressure drop*

Pressure drop can be defined as the reduction in mixture pressure from one point to one point. It occurs when there are obstacles in the pipelines. Tremendous pressure drop will affect low system performance and high energy consumption. High operating pressure drop means higher energy consumptions. (Compressed air challenge)

2.2 *Multiphase flow*

Multiphase flow system is the flow of mixture such as liquid in gas, liquid and solid and more. Multiphase is so important in oil and gas industries but along with it comes with a problem such as pressure drop. This problem does not unique in the industries, thus many researcher have done some experiments to encounter the problem by introducing a correlation. These correlations help the ability of engineer to predict pressure drop in pipelines more accurate. (T.Crowe, 2006)

2.3 *Flow pattern*

First and foremost flow pattern determination one of the most important element in calculating pressure loss. Pipe corrosion and erosion depends on the system flow pattern. Beggs-Brill correlation and Petalas-Aziz correlation depends on the flow pattern in their calculation. Basically there are few types of flow pattern. Beggs and Brill correlation divide the flow pattern into four groups which are segregated, intermittent, transition and distributed whilst Petalas-Aziz correlation divide into 6 major groups dispersed, stratified, annular, bubble and intermittent. This issue will be discussed more in other sections.

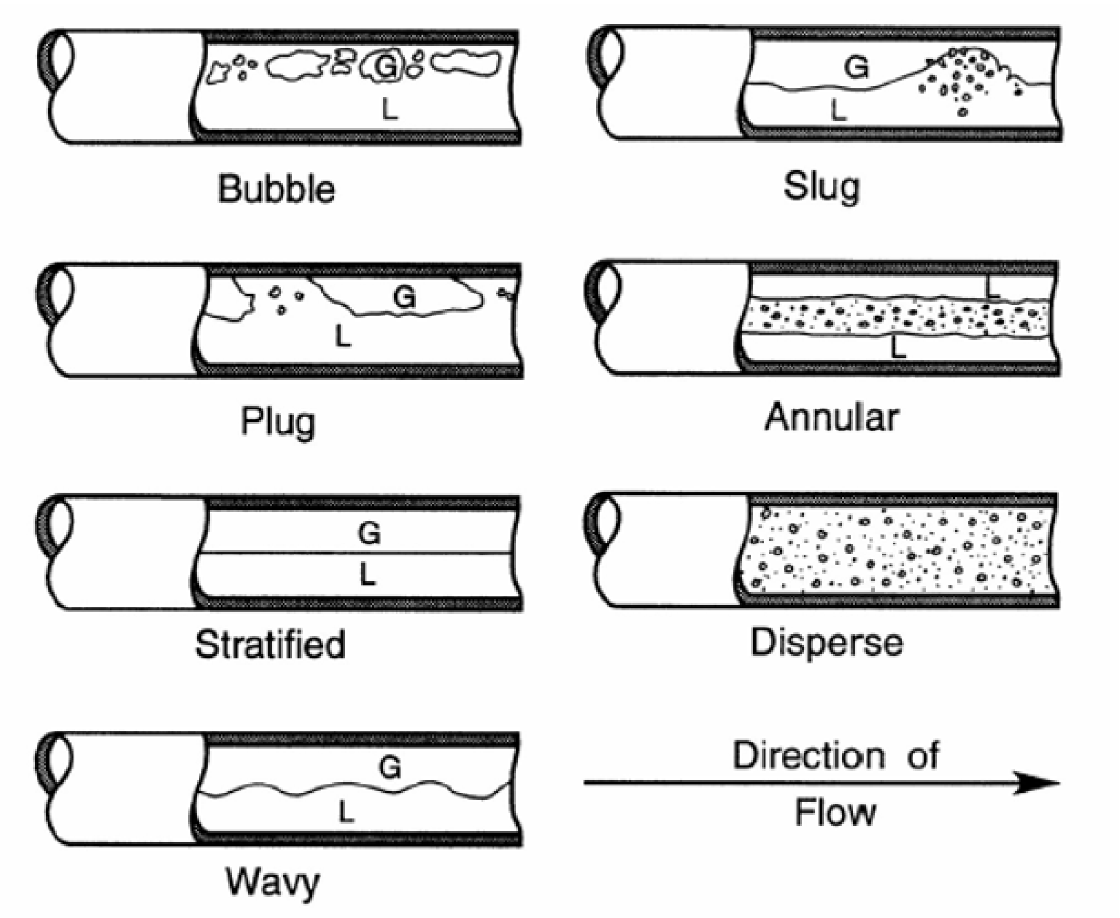

Figure 2-1 Flow pattern in horizontal pipes

Since this study only focus on horizontal pipelines thus Mandhane et al. horizontal flow regime is used to determine the flow pattern regime (Mandhane, G.A, & K, 1974). There are 7 types of flow pattern which is;

a) Bubble
b) Plug
c) Slug
d) Annular
e) Stratified
f) Disperse
g) Wavy

2.3.1 Bubble

High concentration of bubble is formed in the upper half of the tube because of the buoyancy of the bubble. The gas bubbles dispersed when shear forces are bigger, thus the bubbles tend to disperse uniformly. This regime happens at high mass flow rate. (Wolverine Tube,Inc)

2.3.2 Plug

Plug flow has a separated by elongated gas bubbles. The diameter of the elongated bubbles is smaller than the pipelines itself. The liquid phase is continuous along the bottom of the tube below the elongated bubbles. Plug flow regime sometimes called as elongated bubble flow. (Wolverine Tube,Inc)

2.3.3 Slug

Increasing the gas velocities, the elongated bubbles diameter will be same as the pipelines. The liquid slugs that separated the elongated bubbles also described as large amplitude waves. (Wolverine Tube,Inc)

2.3.4 Stratified

Complete separation of the mixture will happen when the gas and liquid in low velocities. Gas exist at top of the pipe while liquid is at the bottom. The mixture completely stratified undisturbed horizontal interface. (Wolverine Tube,Inc)

2.3.5 Wavy

Waves are formed on the interface of the mixture when the gas and liquid velocity is increased. The wave is notable and depends on the relative velocity of the two phase. But the amplitude or top of the waves do not reach the pipelines. Thin films of the liquid are stained on the wall because of the behaviour of the waves. (Wolverine Tube,Inc)

2.3.6 Annular

Continuous annular film is forms around the pipelines. All of this happens when the gas flow rate is increased. The liquid at the bottom is thicker than the top, the surface between the liquid annulus and the vapour core is disturbed by small amplitude waves and droplets. The top of the pipelines with thinner liquid film will dry first because of the high gas fractions. (Wolverine Tube,Inc)

2.3.7 Dispersed

The mixture will be in continuous gas phase at very high gas velocities. The liquid might be striped and become small droplets. (Wolverine Tube,Inc)

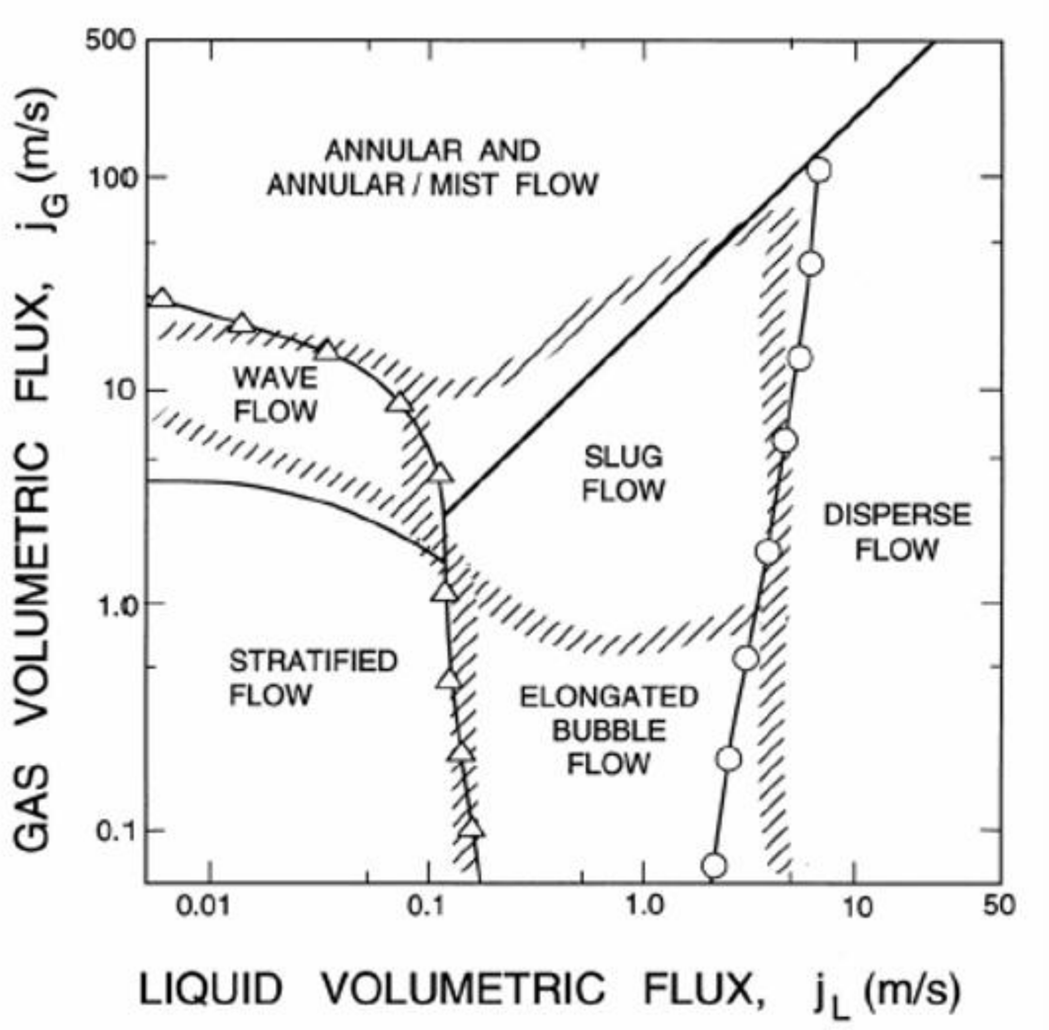

Figure 2-2 Mandhane et al. horizontal flow pattern

2.4 Pressure drop correlation

2.4.1 Beggs and Brill correlation

Beggs and Brill correlation is one of the oldest correlations that have been used up until now. It can predict the pressure drop in all types of angle. Based on figure there 4 types of flow pattern has been mentioned in previous section. For distributed it specified for bubble flow. Stratified, wavy and annular is categorized as segregated. Intermittent stand for plug and slug flow. Segregated is define as annular and stratified flow. Distributed is for bubble flow and transition is for other than the other flow. For this research transition is not determined.

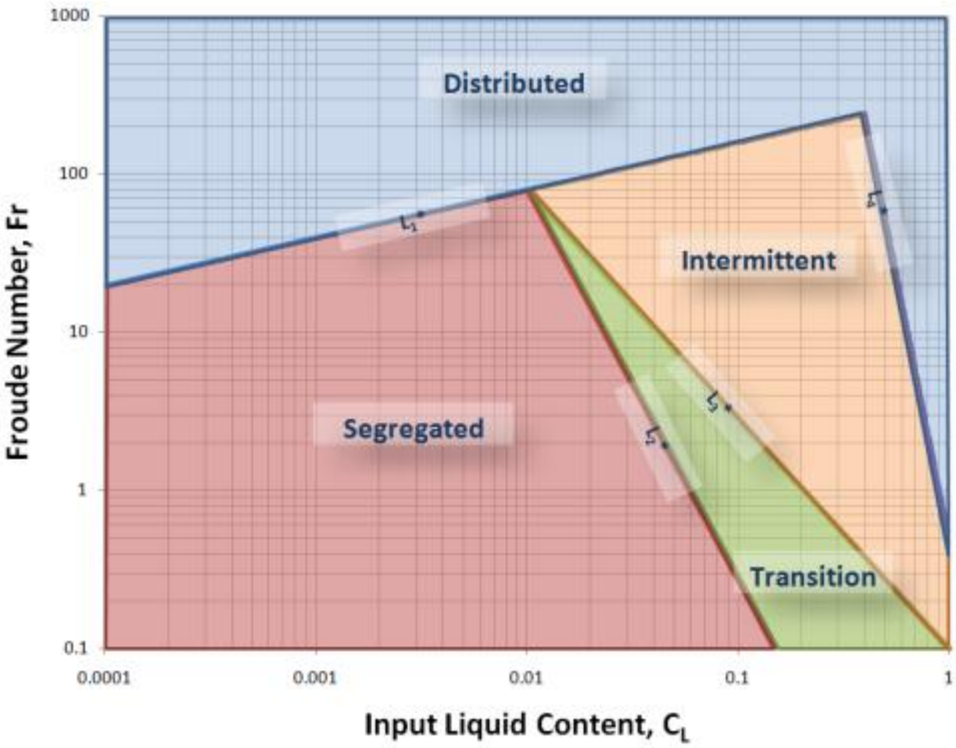

Figure 2-3 Beggs and Brill flow pattern

2.4.2 *Petalas Aziz correlation*

Petalas-Aziz is one of the newest correlation to predict pressure drop. Same as Beggs and Brill correlation, this correlation can calculate any pipe inclinations and all types of fluid. Moreover, this model also uses database more than 20,000 laboratory measurement and data from 18000 wells. Figure shows that for Petalas Aziz consider disperse, bubble, intermittent, stratified, annular and froth. Froth stand for any types of flow pattern mentioned in Petalas-Aziz correlation.

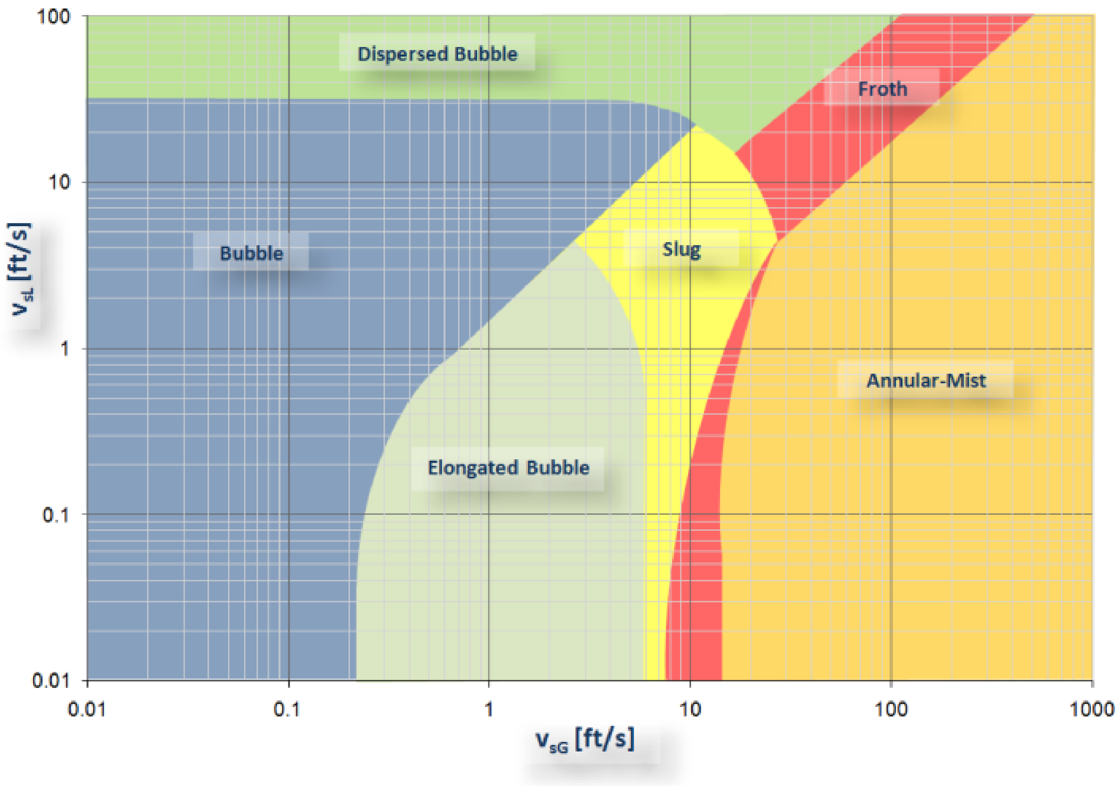

Figure 2-4 Petalas and Aziz flow patern map

2.5 *Software*

FORTRAN stands for FORmula TRANslation. The purpose of the software is for mathematical computations in engineering. This software is the high level programming language. It was developed by Salford Software Limited a company owned by University of Salford.

3 METHODOLOGY

3.1 Overview

In order to predict the pressure drop under multiphase flow conditions, two correlations will be used which is Petalas-Aziz correlation (2000) and Beggs-Brill correlation (1973). Both correlations will consider the flow pattern. Flannigan (1985) does not consider the flow pattern in the correlation but it will be used to compare with other correlation.

Figure 3-1 shows the methodology to solve the pressure loss under multiphase condition. First of all the input parameters are inserted. Natural gas and water properties are used for the input parameters. The diameter of pipes will be varies since different diameter will give a different results in flow pattern and pressure drop. After inserting the input parameters, dimensional parameters are calculated.

After calculating the dimensionless parameters, the flow pattern will be determined. Figure 3-2 shows the methodology to determine the flow pattern. Last but not least is the determination of pressure drop using Beggs-Brill (1985) and Petalas-Aziz (2000) correlations. For Flannigan (1985) the pressure drop is directly calculated based on the input parameters this is because the correlation does not refer the flow pattern.

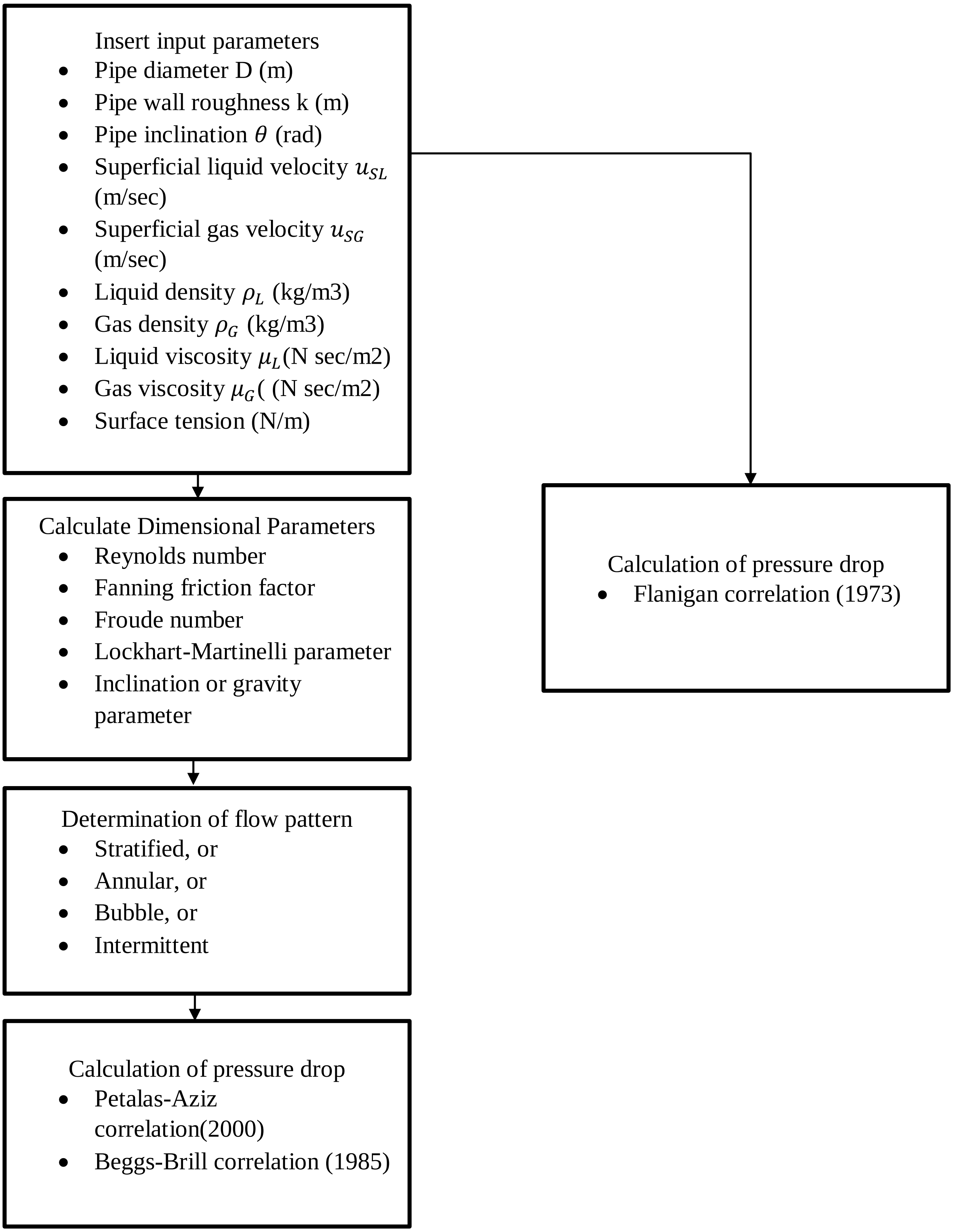

Figure 3-1 Pressure determination methodology

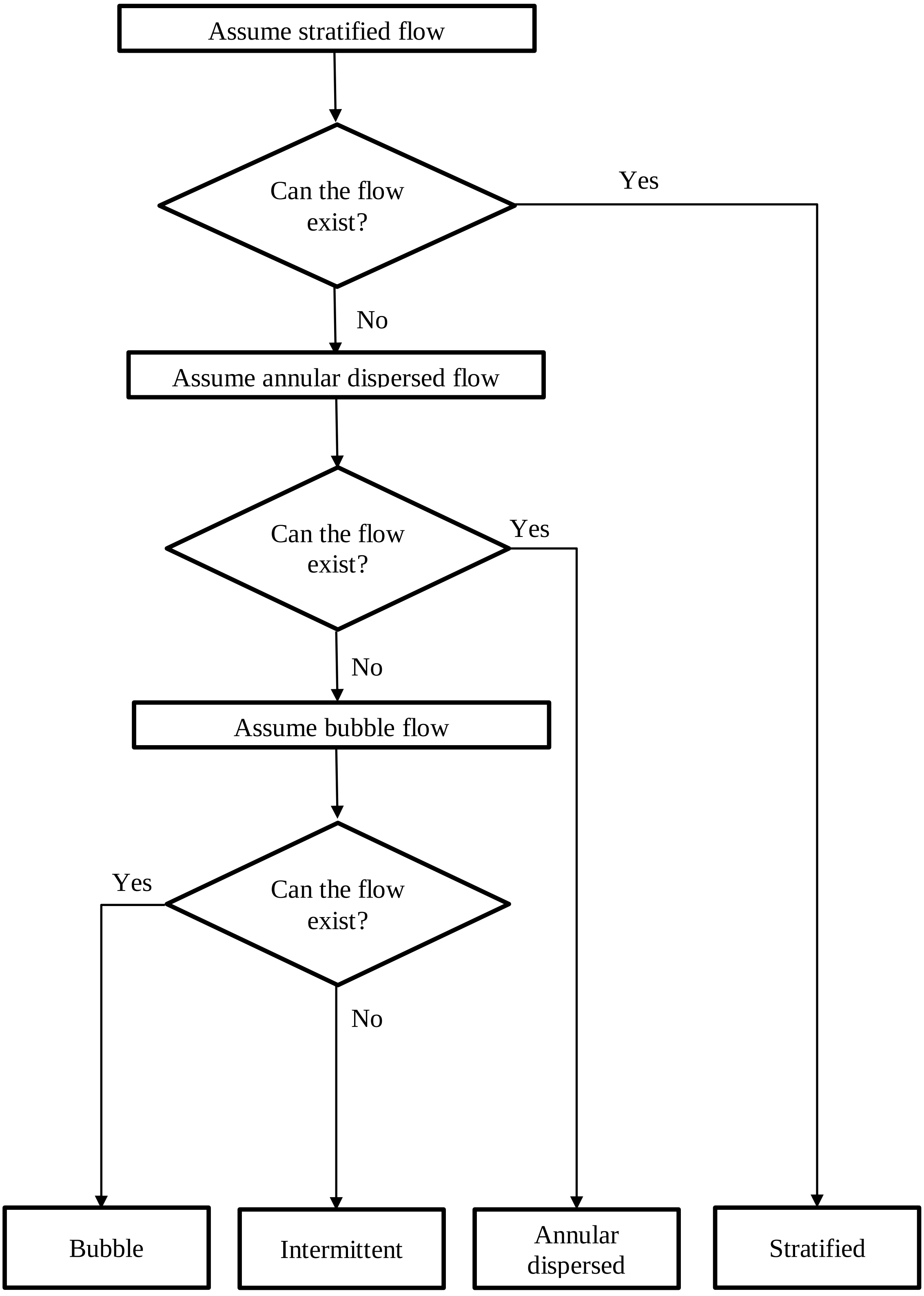

Figure 3-2 Flow pattern determination methodology

3.2 *Determination of flow pattern*

First step to determine the flow pattern some input parameters need to be inserted. First is the diameter of the pipe, D and wall roughness, k. Second is the pipe inclination. But since this studies assume that it will consider horizontal pipe only thus the inclination set to 180°. Next is the properties of the natural gas and crude oil which is superficial liquid velocity u_{SL} (m/sec), superficial gas velocity u_{SG} (m/sec), liquid density ρ_L (kg/m3), gas density ρ_G (kg/m3), liquid viscosity μ_L(N sec/m2) and gas viscosity μ_G((N sec/m2). Last but not least is the surface tension. The value of superficial velocity will be used as in

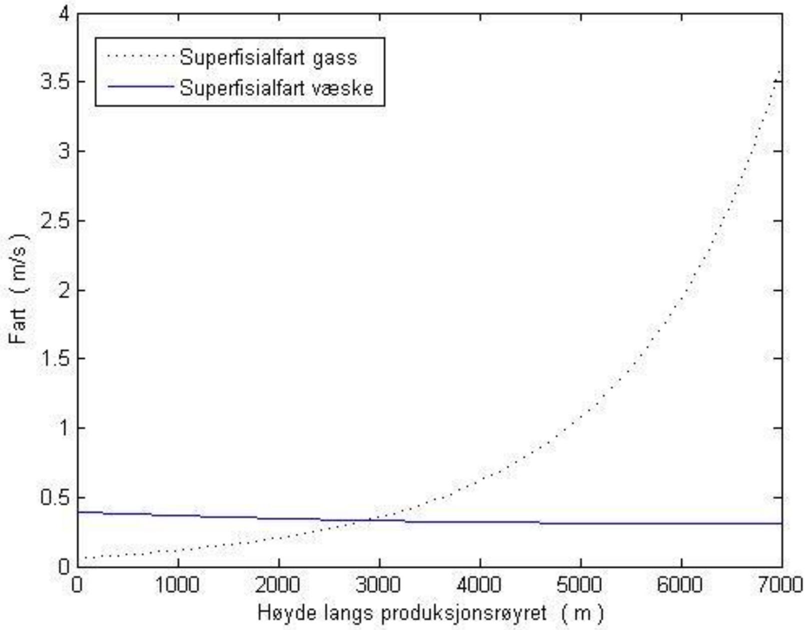

Figure 3-3 Superficial velocity along the pipe

After inserting the input parameters, the second step is calculation dimensionless parameter. First is superficial Reynolds number for gas and liquid. Reynolds number used to determine whether the mixture flow as turbulent, laminar or transition. If the value of Reynolds number is greater than 4100 the command window will show “The flow is laminar” and if the Reynolds number calculated is more less than 2300 the command window will show “The flow is turbulent”. But if the value of is between 2300 and 4100 the program will not run since this study only consider laminar and turbulent flow.